ABSTRACT

Ground wave radio propagation can be used for estab-
lishing an over-the-horizon communications circuit on the Moon.
A method for computing the required transmitter power for this
circuit using frequencies in the 100 kHz to 10 MHz band is
presented here. In general, frequencies above this band tend
to be highly attenuated, while equipment limitations at fre-
quencies below this band preclude adequate bandwidth for communi-
cations.

Principal parameters of interest are the propagation
loss, antenna gains and received noise power. Propagation loss
increases with increasing frequency, path length, and/or height
of the intervening terrain. Antenna gain increases with in-
creasing frequency, while noise effects decrease with increasing
frequency.

As shown in a sample calculation, only 250 milliwatts
of transmitted power at 3 MHz, and a 15 meter transmit monopole
antenna are required to establish a voice circuit over a
hypothetical 5 kilometer lunar path. Thus, from the standpoint
of equipment weight and power limitations ground wave
propagation in this frequency band is an attractive technique
for establishing over-the-horizon communications on the Moon.

Irregular terrain features, such as craters, hills,
etc., which intercept the radio path could substantially
increase ground wave attenuation. Empirical data is required
on transmission over Earth paths with electrical and physical
characteristics similar to the lunar surface to provide better
estimates of the excess ground wave attenuation on lunar paths
containing these irregularities.

SUBJECT: Required Transmitter Power for
Ground Wave Radio Propagation
Beyond the Lunar Horizon in the
100 kHz to 10 MHz Frequency Band
Case 320

DATE: July 23, 1969

FROM: K. H. Schmid

MEMORANDUM FOR FILE

1.0   INTRODUCTION

Because of the irregular terrain and curvature of
the lunar surface, line-of-sight radio propagation on the
Moon quickly becomes obstructed as the distance between ter-
minals increases. Certain other Earth-type propagation tech-
niques are either unsuitable or impossible for use on the Moon.
For example, knife-edge diffraction at microwave frequencies
requires a sharp mountain peak or cross-path ridge between
the terminals; this configuration won't exist in most cases.
Ionospheric reflection or tropo-scatter propagation used on
Earth is not possible on the Moon due to the absence of an
atmosphere.

Thus, either two-way Earth relay or ground wave
propagation over the lunar surface remain as possible tech-
niques for establishing lunar communications beyond the horizon.
Ground wave propagation in the 100 kHz to 10 MHz frequency band
is investigated here. In general, frequencies above this band
tend to be highly attenuated, while equipment limitations at
frequencies below this band preclude adequate bandwidth for
communications between the landed lunar module (LM) and the
extra-vehicular astronaut (EVA) or lunar roving vehicle (LRV).

To compute the required transmitter power, the propa-
gation loss, antenna gains and received noise power are param-
eters that must be determined. Each of these parameters is
discussed in the next paragraphs. Finally, a sample calculation
for determining the required transmitter power on a five kilo-
meter, over-the-horizon circuit at a frequency of 3 MHz is
presented.

2.0   PROPAGATION LOSS

Ground wave propagation loss between isotropic
antennas is given by:

$$L_p = 32.45 + 20 \log d_{km} + 20 \log F_{MHz} + A_t + A_o \quad dB$$

where:

d_{km} = distance between antennas in km.

F_{MHz} = frequency in MHz

A_t = ground wave attenuation due to smooth and curved lunar terrain

A_o = ground wave attenuation correction factor for irregular lunar terrain.

The first three terms are simply the free space loss. The ground wave attenuation due to smooth and curved lunar terrain, A_t, is derived from a set of curves presented in Reference 1. A sample of these curves is given in Figures 1 and 2. From Figure 2, note that A_t increases with increasing frequency and distance. The term, A_o, has been calculated for a number of idealized* terrain features in References 2 and 3.

Reference 2 describes the case of a smooth, poorly conducting, cylindrical shaped hill between the two antennas. A curve of A_o as a function of hill height, path length, and wavelength is reproduced in Figure 3.

The case of a perfectly conducting curved surface with a knife-edge obstacle on the path is described in Reference 3. Curves of A_o as a function of knife-edge height, path length, position of the knife-edge on the path, and wavelength are presented in Reference 3.

3.0 ANTENNA GAIN

For mobile use, the vertical monopole antenna appears to be the most practicable. This antenna is omni-directional in the horizontal plane and is easily mounted on the LM, EVA or LRV. (Other types of antennas of interest here are the horizontal dipole and the Beverage antenna; however, both of these antennas are semi-fixed and directional in the horizontal plane.)

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*Empirical data is needed to estimate A_o for random and irregular terrain features on the Moon, e.g., craters and hills, which intercept the radio path.

The gain above isotropic (G_t-L_t) of a 15 meter transmit monopole antenna is about -44 dB at 100 kHz and increases at about 12 dB per octave of frequency up to 1 MHz (Figure 4). The large negative gain is attributed to the ground proximity loss, L_t.

Since a 15 meter monopole antenna is short compared to any wavelength in the 100 kHz to 1 MHz frequency band, the antenna must be tuned. While tuning provides increased radiated power, a narrowband system is the undesirable result. Tuning assumed in Figure 4 provides a bandwidth of 2.5 kHz. To increase the bandwidth to 10 kHz, an impedance matching, reactive (lossless) network in combination with a resistive loading network could be used. For frequencies approaching 10 MHz, the monopole antenna becomes increasingly more resonant, and less tuning is required to achieve the desired bandwidth.

4.0 NOISE EFFECTS

For a 15 meter receive monopole antenna, the major contributor of noise power to the receiving system is galactic noise. The noise power from this source can be characterized by an external noise factor, f_e. Empirical data taken by Menzel and Hartz (Figure 5) indicates that f_e can be approximated by:

$$f_e = 5.012 \cdot 10^4 \ F_{MHz}^{-1.8} \qquad (0.5 \leq F_{MHz} \leq 10) \qquad \text{(Hartz)}$$

$$f_e = 1.585 \cdot 10^5 \ F_{MHz}^{-2.3} \qquad (10 \ \leq F_{MHz} \leq 200) \qquad \text{(Menzel)}$$

$$f_e = 6.467 \cdot 10^6 \ F_{MHz}^{-3} \qquad (F_{MHz} > 200) \qquad \text{(Menzel)}$$

Other thermal noise generators such as ground ohmic losses, transmission line loss and the receiver contribute negligible amounts of noise compared to the galactic (external) noise.

5.0 SAMPLE CALCULATION

A sample calculation of required transmitter power is presented here. The assumed terrain characteristics described in Table I approximate a path profile (Profile B) extending from an actual Apollo landing site (Littrow). Thus, this hypothetical case is representative of lunar terrain which will be encountered on future missions.

TABLE I: Terrain Characteristics

Distance (d_{km})	5 km
Terrain	Smooth cylindrical hill with height = 100 m.
Number of Soil Layers*	2
Upper Layer Height, (1_1)*	1000 m.
Soil Conductivity, Upper Layer, (σ_1)*	10^{-4} mho/m.
Soil Conductivity, Lower Layer, (σ_2)*	10^{-2} mho/m.
Dielectric Constant, Upper Layer, (ε_{r1})*	2
Dielectric Constant, Lower Layer, (ε_{r2})*	20

The last six of these characteristics are applicable to Figure 1. The parameters K_V and B_V° determined from Figure 1 are required to evaluate A_t in Figure 2.

Circuit characteristics associated with this hypothetical link are shown in Table II.

TABLE II: Circuit Characteristics

Frequency (F_{MHz})	3 MHz
Receive Antenna Gain (G_r) (including line loss)	0 dB
Required SNR (SNR_{req})	15 dB
Bandwidth (B)	10 kHz

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*Parameters taken from "A Study of Lunar Surface Radio Communication" (see Reference 1).

To determine the required transmitter power the following equation is applicable:

$$P_t = 32.45 + 20 \log d_{km} + 20 \log F_{MHz} + A_t + A_o + (L_t - G_t)$$

$$- G_r + SNR_{req} + F_e + B + 10 \log k\, T_o \qquad dBW$$

For this example the equation yields,

(a) $\qquad\qquad 20 \log d_{km} = 14.00 \text{ dB}$

(b) $\qquad\qquad 20 \log F_{MHz} = 9.55 \text{ dB}$

(c) A_t: The characteristics listed in Table I dictate the use of Figure 1 to determine the two parameters, K_V and $B_V^{\,o}$. Thus,

$$K_V = 0.04 \text{ and } B_V^{\,o} \approx 90°$$

A_t is plotted vs. $X_o^1 = F_{MHz}^{1/3} d_{km}$ in Figure 2. Thus,

$$X_o^1 = 3^{1/3}\, 5 = 7.22$$

and

$$A_t = 32 \text{ dB.}$$

(d) A_o: This parameter is derived from Figure 3. To use this Figure, d/λ and h/λ must be calculated, where d is path distance, h is hill height, and λ is wavelength.

Thus,

$$\frac{d}{\lambda} = \frac{5000}{100} = 50; \qquad \frac{h}{\lambda} = \frac{100}{100} = 1$$

Therefore, $A_o = 10.6 \text{ dB.}$

(e) (L_t-G_t): The term (G_t-L_t) is taken from Figure 4. Thus,

$$L_t-G_t = 6 \text{ dB (including line loss)}$$

(f) $G_R = 0$ dB from Table II

(g) $SNR_{req} = 15$ dB from Table II

(h) $F_e = 10 \log f_e$:

$$10 \log (5.012 \cdot 10^4 \frac{1}{F_{MHz}^{1.8}}) = 7.0 + 40 - 8.6 \text{ dB}$$
$$= 38.4 \text{ dB}$$

(i) $B = 10 \log 10^4 = 40$ dB

(j) $10 \log k T_o = -204$ dBW/Hz

where k = Boltzmann's constant

$T_o = 290°K$ reference temperature

(k) Therefore, $P_t = -6$ dBW (250 milliwatts)

6.0 SUMMARY AND CONCLUSIONS

        A method for computing the required transmitter power
for ground wave propagation beyond the lunar horizon has been
presented. Principal parameters of interest are the propa-
gation loss, antenna gains and received noise power. Propagation
loss increases with increasing frequency, path length and/or
height of intervening terrain. Antenna gain increases with
increasing frequency, while noise effects decrease with in-
creasing frequency.

As shown in the sample calculation, only 250 milli-watts of transmitter power at 3 MHz is required to establish a voice circuit over a hypothetical 5 kilometer lunar path. Thus, from the standpoint of equipment weight and power limitations ground wave propagation in the 100 kHz to 10 MHz frequency band is an attractive technique for establishing over-the-horizon communications on the Moon.

At present, empirical data is needed to estimate A_o for random and irregular terrain features on the Moon, e.g., craters and hills, which intercept the radio path. These features may substantially increase the ground wave propagation loss and consequently, higher transmitter power may be required to sustain a circuit over irregular terrain as compared to smooth terrain. Transmission measurements on Earth, over surfaces with physical and electrical parameters similar to that on the lunar surface, would provide such empirical data and are recommended for future tests.

K. H. Schmid

2034-KHS-ulg   K. H. Schmid

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REFERENCES

1. Vogler, L. E., "A Study of Lunar Surface Radio Communication", NBS Monograph 85, dated 14 September 1964.

2. Wait, J. R. and K. P. Spies, "Radio Propagation Over a Cylindrical Hill Including the Effect of a Surmounted Obstacle", IEEE Transactions on Antennas and Propagation, November 1968.

3. Wait, J. R. and K. P. Spies, "On the Diffration by a Knife-Edge Obstacle on a Conducting Earth", Radio Science, December 1968.

4. Wild, J. W. and V. B. Morris, Jr., Final Study Report, Communications and Control for Lunar Exploration Systems - Apollo, Westinghouse Defense and Space Center, Systems Operations Division, dated March 1965.
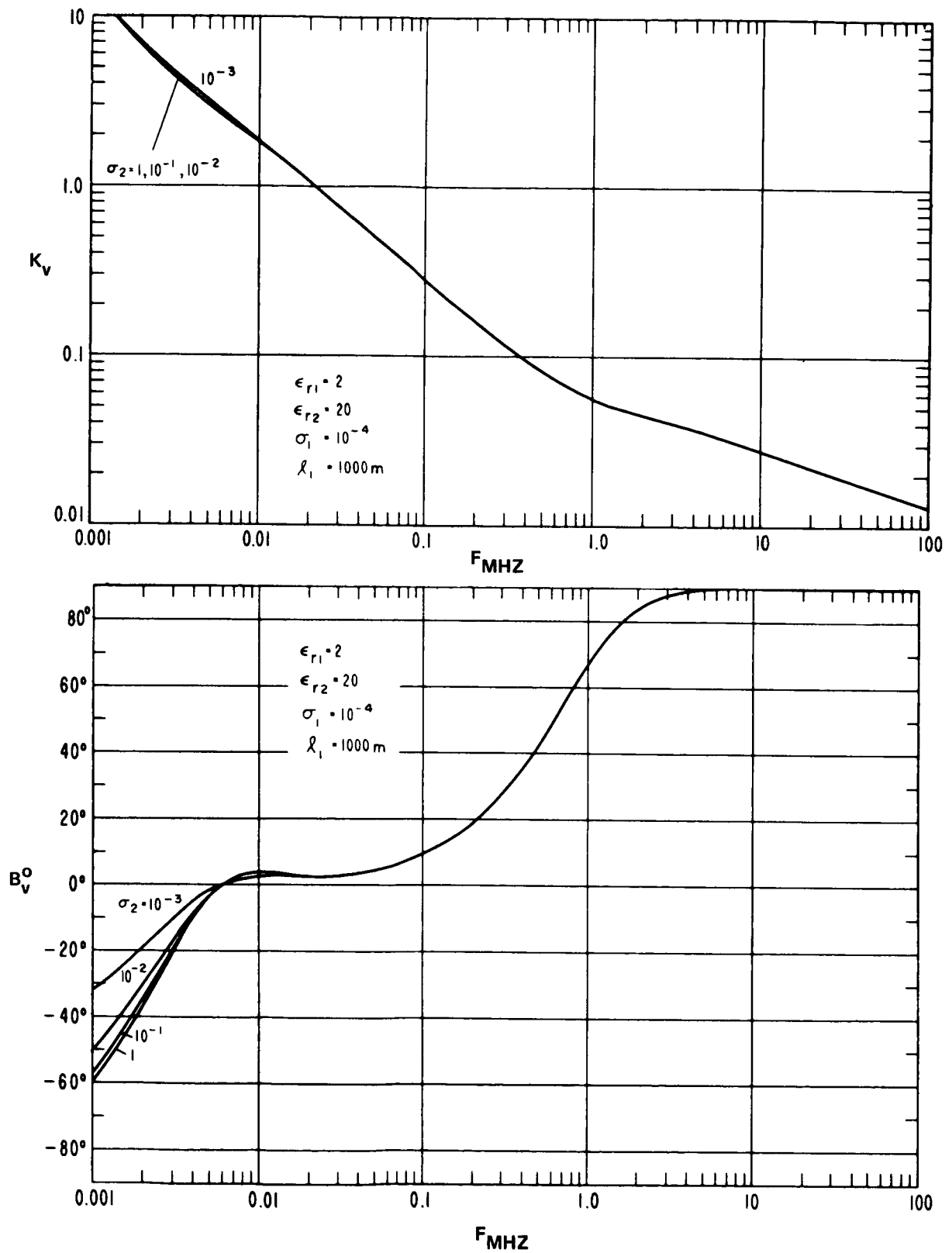
FIGURE 1 K_v AND B_v^o FOR TWO LAYERS, UPPER LAYER HEIGHT: 1000 m.
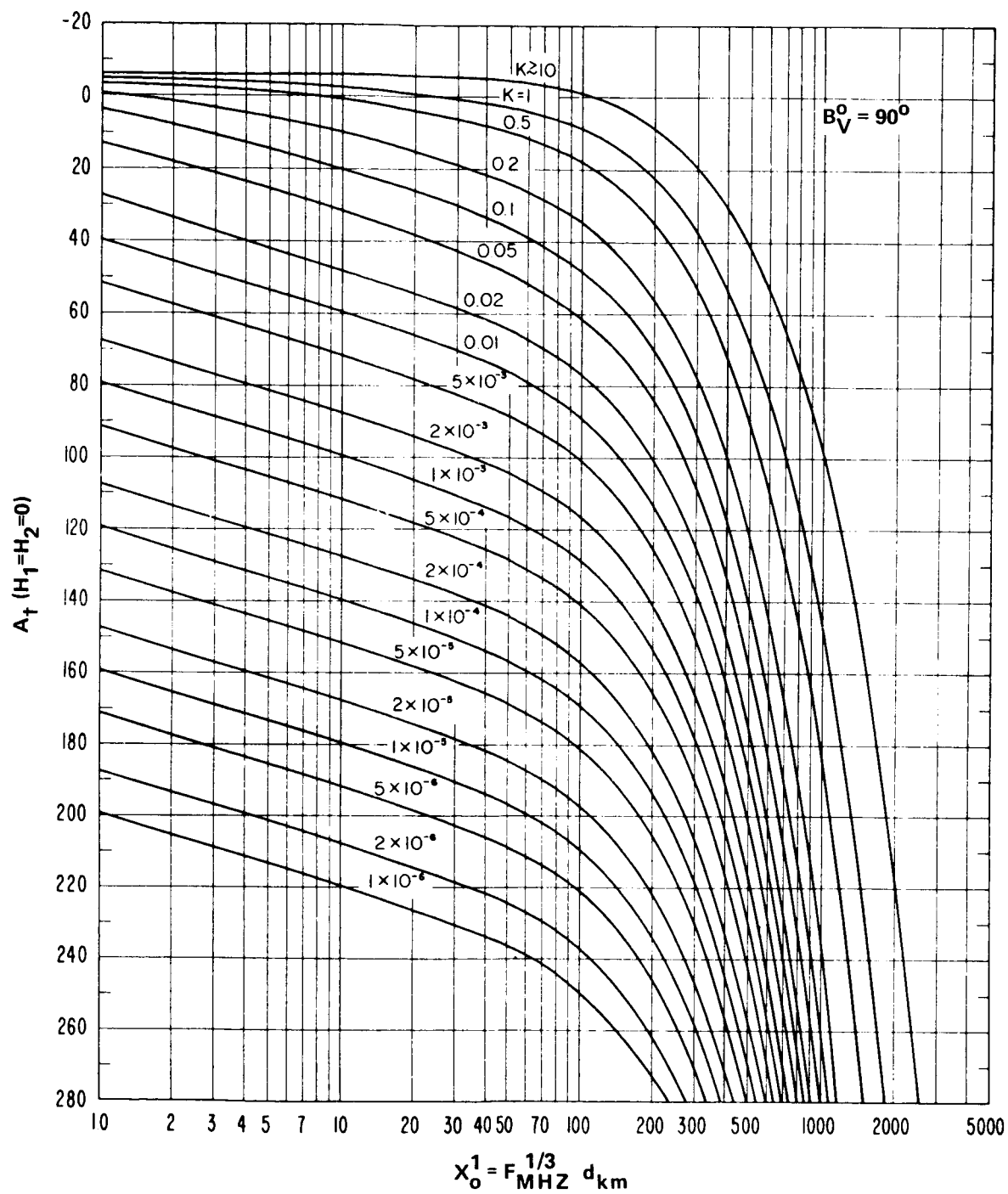
FIGURE 2 - GROUND WAVE ATTENUATION FOR ZERO ANTENNA HEIGHTS,
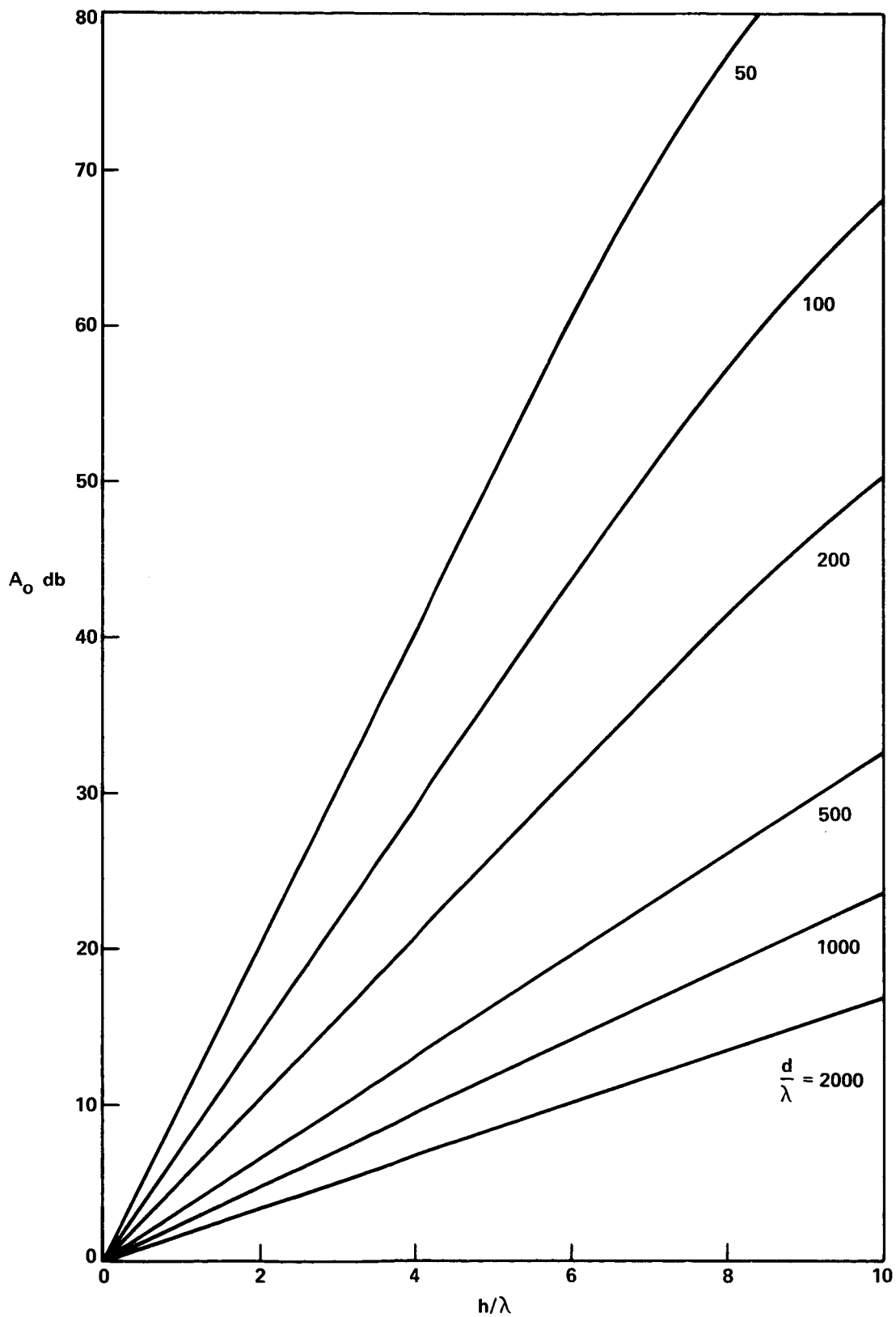$B_V^O = 90^O$ (FROM REFERENCE 1)

FIGURE 3- EXCESS ATTENUATION (REFERENCED TO FLAT SURFACE) DUE TO
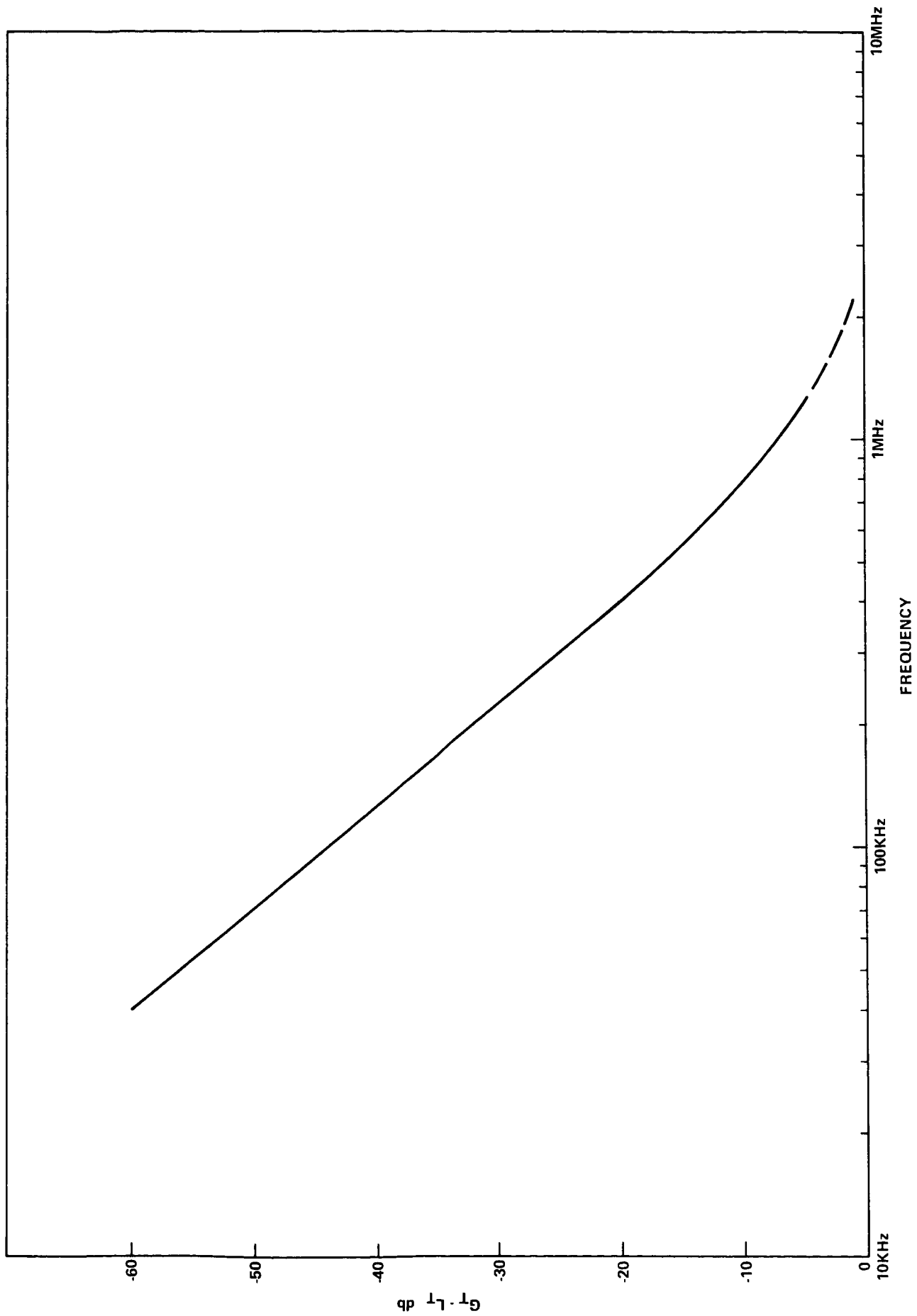A SMOOTH HILL BETWEEN ANTENNAS. FROM REF. 2

FIGURE 4 - ANTENNA GAIN LESS GROUND PROXIMITY LOSS FOR 15 METER MONOPOLE ANTENNA (TUNED). BW= 2.5 KHz FROM REF. 4.
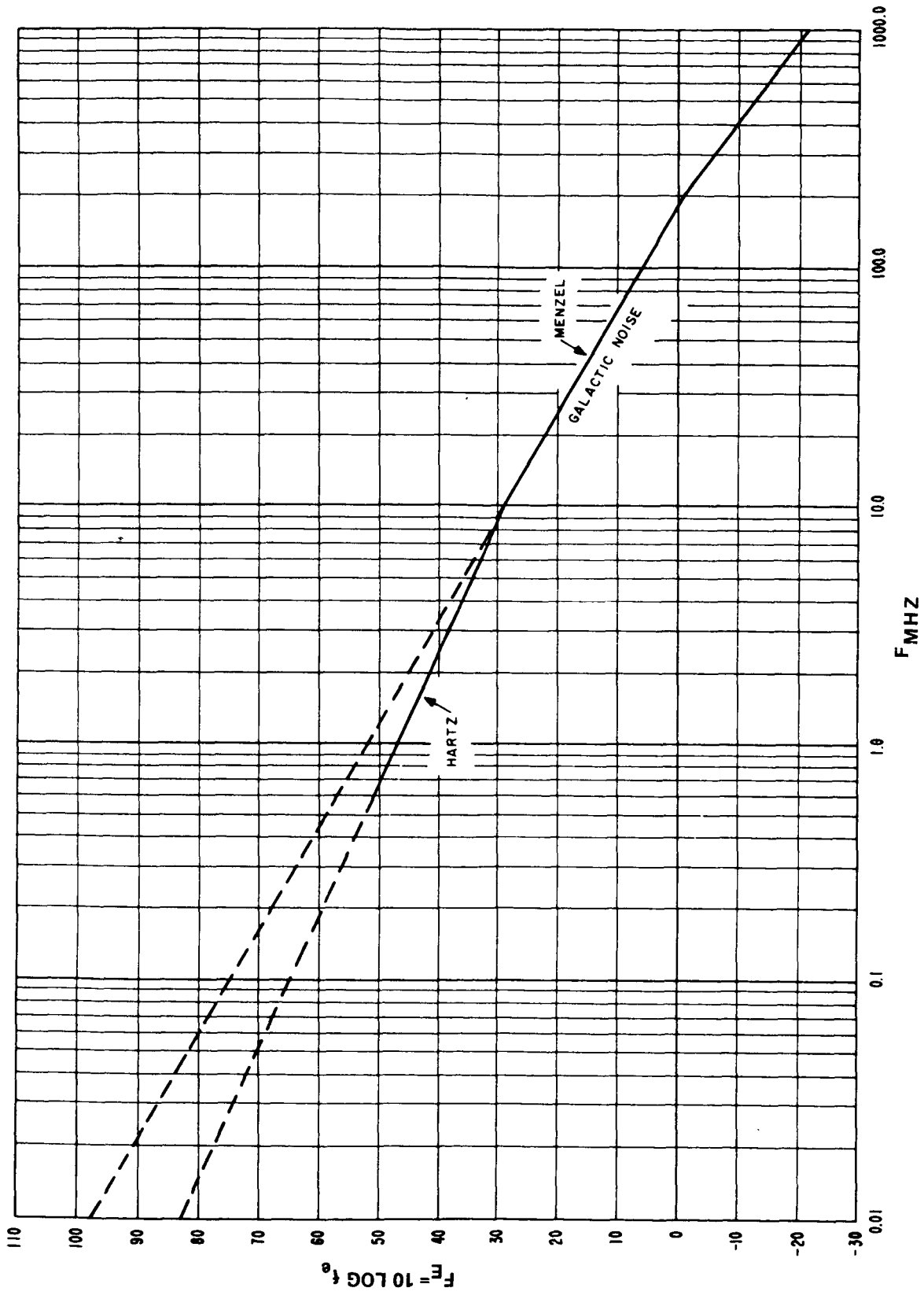
FIGURE 5 - EXTERNAL NOISE FACTOR, F_E, CONSIDERING GALACTIC NOISE ONLY.   (FROM REFERENCE 1)

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